



Net-zero power

Long duration energy storage
for a renewable grid

Introduction prior to panel

March 2022



McKinsey
& Company

The LDES Council was founded in 2021 to address some of the big questions on the role of energy storage to achieve net zero

Technology providers



Anchors

Industry and services customers



Capital providers



Equipment manufacturers



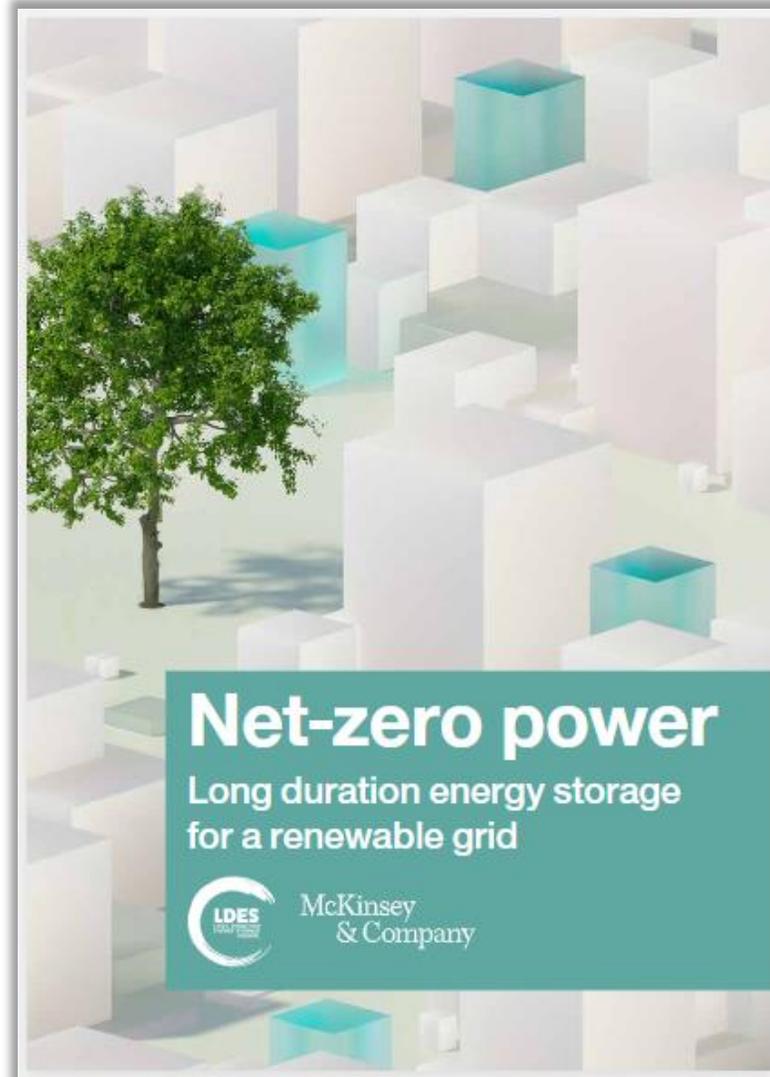
Low-carbon energy system integrators & developers



Key principles of the LDES Council

-  CEO-led
-  Global
-  Fact-based
-  For societal benefit
-  All types of energy storage, not just electrochemical

The inaugural report of the LDES Council was launched at COP26



1. Introduction

Chapter summary
LDES can have a role to play in increasing power system flexibility, which will be crucial to achieve net-zero.

The decarbonisation of power systems by 2040 will be essential to achieve net-zero emissions and limit the rise in global temperatures to 1.5°C.

High renewable penetration will have an impact on the reliability and stability of the power system. This is due to the intermittent nature of wind and solar, which means that there are times when there is no power being generated. This means that there are times when there is no power being generated. This means that there are times when there is no power being generated.

- Interday flexibility (17 continuous hours)
- Making and making flexibility (17 hours)
- Seasonal flexibility
- Flexibility to respond to extreme weather events

Wind solutions exist today, they are other carbon emitting (such as gas plants), physically constrained (such as large scale pumped storage hydro power, or PSH) or are not cost effective for addressing all these needs of the power system (such as them on batteries). LDES can provide effective energy storage, long duration energy storage (LDES) technologies are required.

Power rapidly and demand imbalance

- Change in renewable flow patterns
- Decrease in system inertia

These three challenges are tackled by increasing flexibility in the power sector across different time scales.

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2. LDES technologies characterization and current status

Chapter summary
LDES technologies can play a critical and unique role delivering flexibility on times ranging from hours to weeks.

LDES technologies, the other forms of electricity storage, allow energy to be stored at times when energy supply exceeds demand and released at times when energy demand exceeds supply.

Novel LDES technologies have distinctive features relative to other forms of electricity storage.

Novel LDES technologies have been deployed today.

- They have relatively low load times compared to batteries and distributed (DG) grid storage and regulation
- They are widely deployable and scalable to long-term storage requirements.

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3. Modeling the flexibility needs of future power systems

Chapter summary
LDES technologies need to be scaled dramatically over the next 20 years to enable a net-zero power system.

Modeling shows that in a net-zero scenario, the total electricity demand (TDE) for LDES rises to 100 TWh per year by 2040, up from 10 TWh in 2020. This is a 10x increase in electricity demand for LDES.

LDES is a key enabler to meet this demand. It provides a flexible and scalable solution to meet the growing demand for electricity storage.

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4. Cost analysis

Chapter summary
Achieving the scales outlined in this report requires learning rates comparable to other emerging clean technologies to occur.

Novel LDES are nascent technologies that will reduce in cost as they are scaled. The Council has identified that a large portion of the costs will be learning curve.

Progressive cost learning rates are between 10% to 30% per year, consistent with other emerging clean technologies such as offshore wind and solar. Technology development and gaining operational scale will be the largest drivers of cost improvements.

The competitiveness of LDES is often largely a function of energy storage capacity costs, which are expected to decline by 50% over the next 10 years. The total system cost of LDES is expected to be reduced by 50% to 75% over the next 10 years.

Some technologies are competitive today for a limited but growing number of applications. The lowest cost of storage (LCOS) ranges from 10 to 20 \$/MWh. This is comparable to other emerging clean technologies such as offshore wind and solar.

In 2020, LDES can be LCOS competitive against 1.5 kWh for duration above 10 hours, with a discharge advantage above 10 hours.

In 2040, LDES can be LCOS competitive against high-purity natural gas with the same operational profile for duration below 10 hours.

To overcome the current cost gap and technological uncertainties of the nascent market, the right mix of policy and investment incentives should be in place.

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5. LDES business cases

Chapter summary
LDES can create significantly economic and environmental benefit in the energy system if opportunities are created to pursue it.

LDES assets are being commercially installed today, being driven by investment of more than 10 percent.

LDES must achieve optimal cost, decrease and performance improvements, as well as technical maturity.

LDES value creation could benefit a wide range of customer and end-user.

Business cases illustrate the potential for value creation in the short term for some of the applications. Integrated value with other revenue streams (batteries, solar, wind, etc.) can have a significant impact on the overall business case.

Market support mechanisms and regulatory incentives are required to the short term to attract the competitiveness of certain business cases and attract the necessary private capital.

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6. Road to competitiveness and key market enablers

Chapter summary
Three potential actions could help unlock LDES value by changing the way storage is regulated and remunerated.

Driving the economic and technical maturity of LDES technologies should be aligned with the large-scale deployment of LDES to achieve maximum societal cost reduction.

A supportive regulatory and market framework would be beneficial to the growth of LDES in the market. Key areas for action have been identified:

1. Long-term system planning could help attract additional levels of private investment.
2. National system planning to address the rapidly rising grid infrastructure and storage.
3. Market creation to ensure the conditions along the lifetime of the assets.

Market mechanisms and designs to ensure compensation for the flexibility provided:

- Funding opportunities to address LCOS uptake (e.g. safety standards, market rules, that support LDES uptake).

A risk of supportive market could significantly delay the deployment of LDES technologies and scaling up capabilities to lower the cost of LDES.

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Findings: LDES will play a major role in net-zero power systems

Renewable penetration and LDES cost-down potential...

60-70%

% renewables of overall capacity for widespread LDES deployment

... leads to widescale LDES deployment and positive business cases

1.5-2.5 TW

Total deployed LDES by 2040

USD 1.5-3 tr

Total investment in LDES capex required by 2040

~60%

LDES cost reduction expected by 2040, driven by scale, innovation and supply chain improvements

3-15%

IRR range for example modelled LDES applications¹

>50%

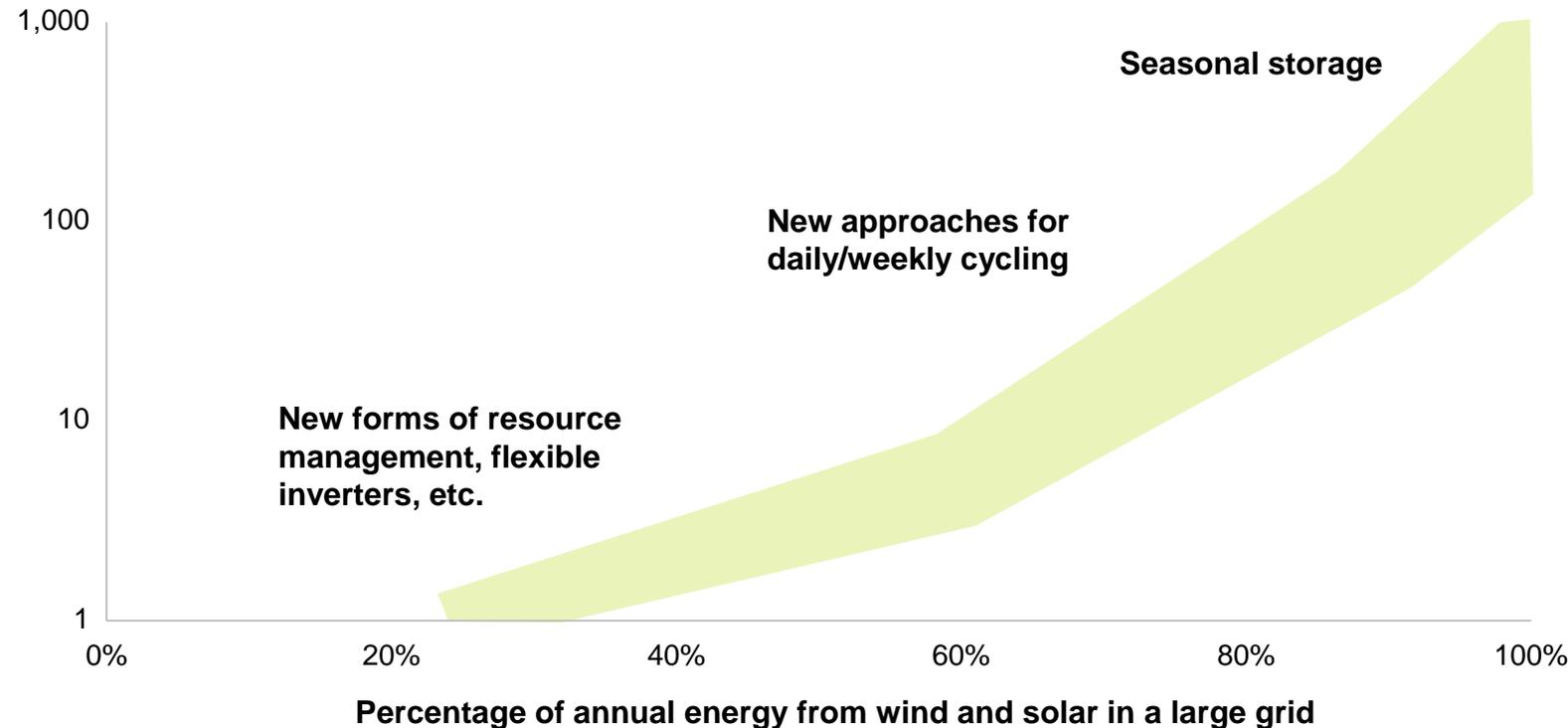
LDES as portion of all installed power flexibility capacity in 2040

1. Excluding potential improvement from implementing market mechanisms, regulatory adjustments, and carbon prices

Flexibility is critical for decarbonisation of power systems

Adoption curve of longer flexibility durations accelerates at 60-70% RE penetration

Storage duration, hours at rated power



RES integration leads to new system challenges



Power supply and demand not always in balance



Transmission flow changes potentially require costly and lengthy transmission upgrades



Retirement of conventional, synchronous generators creates need for new sources of grid support services, e.g., reactive power, inertia

LDES typically offers two major value propositions

Energy shifting



Time horizon	Role of storage	Typical solution
Intraday	Balance variable daily generation with load	8-24 hours LDES
Multiday, multiweek	Support multi-day imbalances Absorb surplus generation to avoid grid congestion	24+ hours LDES
Seasonal duration	Support during seasonal imbalances Mitigate extreme weather events	Hydrogen



Grid services



Grid services offered by LDES

Inertia

Fast frequency response (FFR)

Primary/secondary/tertiary reserve

Reactive power/voltage control

Short circuit level improvement

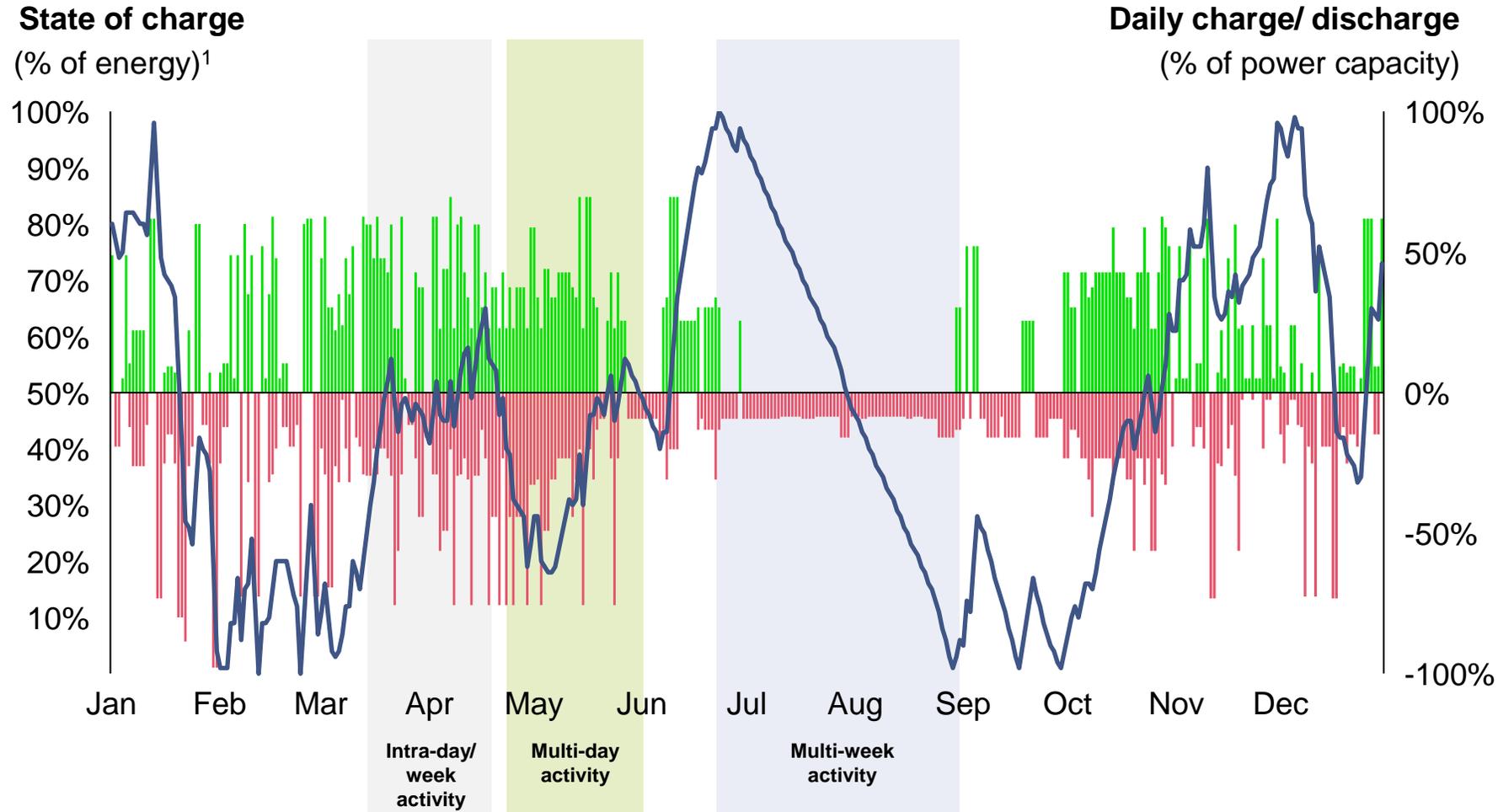
System restoration/ black start

Note: services are technology-specific

We observe LDES playing multiple roles across intra-day, multi-day and multi-week cycling

State of Charge and daily operation, US NYISO LDES installation, 2040

— State of charge ■ Charge ■ Discharge

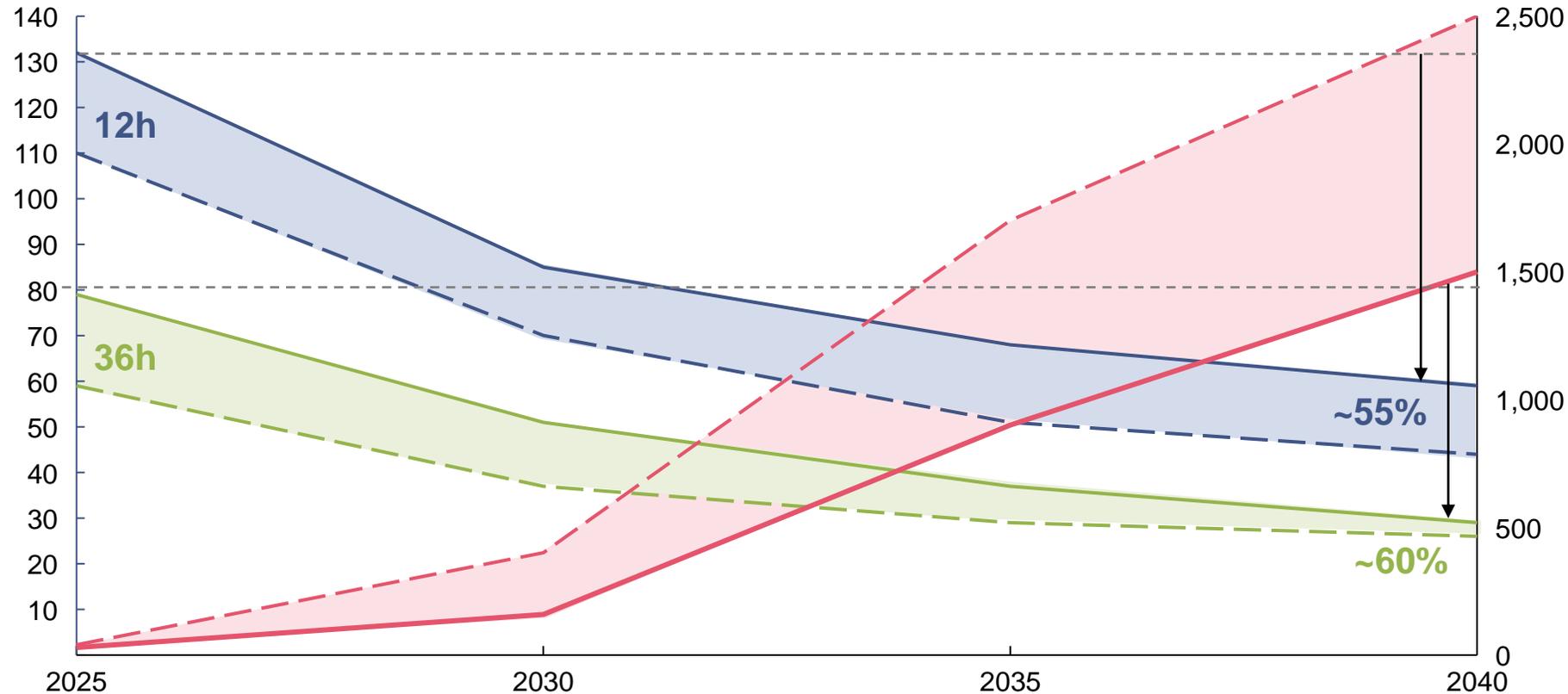


Cost performance is expected improve sharply (-60% by 2040), boosting capacity deployment

LDES capex evolution vs. power capacity additions

■ 12h LDES capex, USD/kWh ■ 36h LDES capex, USD/kWh ■ Cumulative installed capacity, GW
 — Central (conservative learning rate) - - Progressive (ambitious learning rate)

LDES capex (power & energy), USD/kWh



Insights

- Cost reduction driven by
- Scale effects
 - Technology advancements
 - Increasing supply chain efficiency

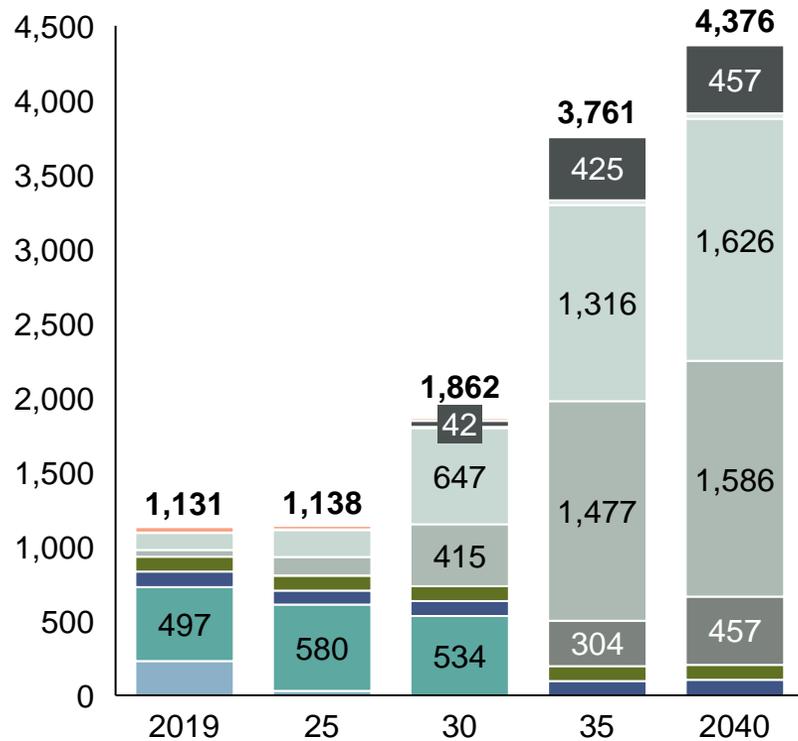
In the US, LDES could make up ~56% of new flexible capacity

(%) LDES share of new flexible capacity⁵

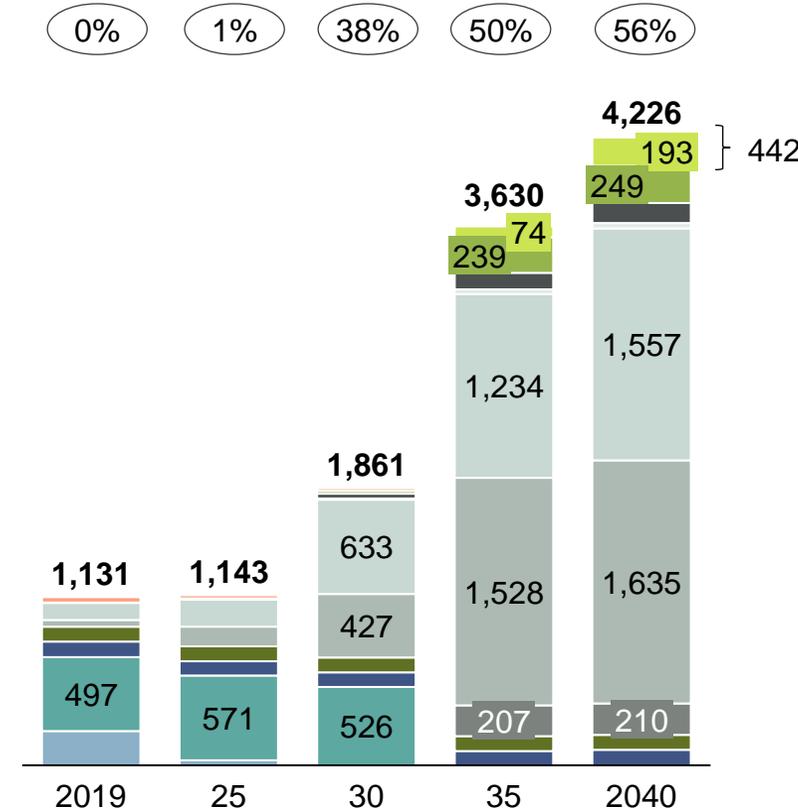


Capacity mix, GW

No LDES



With LDES (Central scenario)



Insights

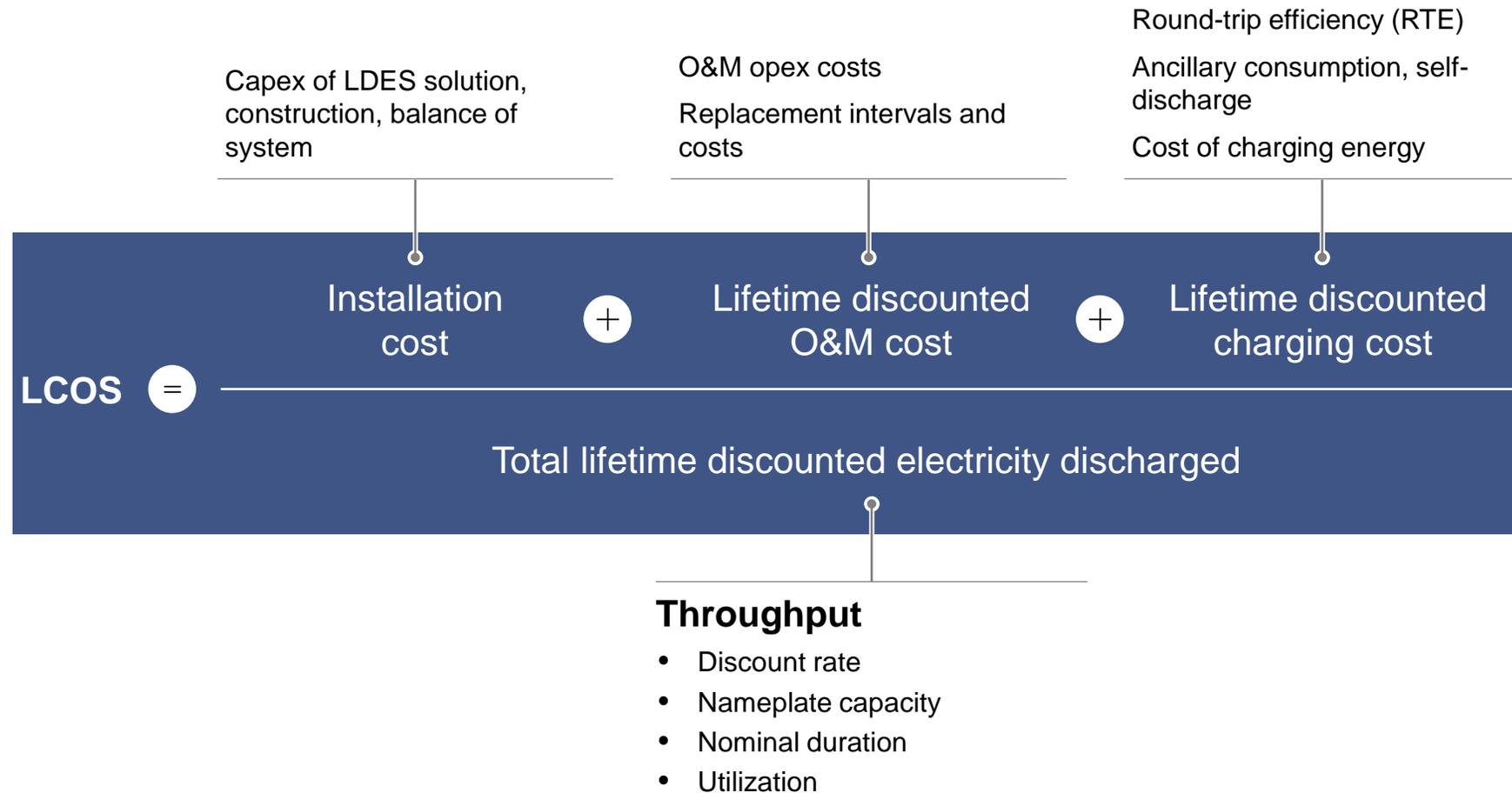
LDES archetypes expected to play major role within "new flexible capacity" (i.e. Li-ion, H2 turbines, LDES)

Until 2030, existing gas limits LDES

By 2040, >50% of new flexible capacity might be LDES systems

Source: McKinsey Power Model

LCOS used to compare cost competitiveness of LDES in realistic operating conditions



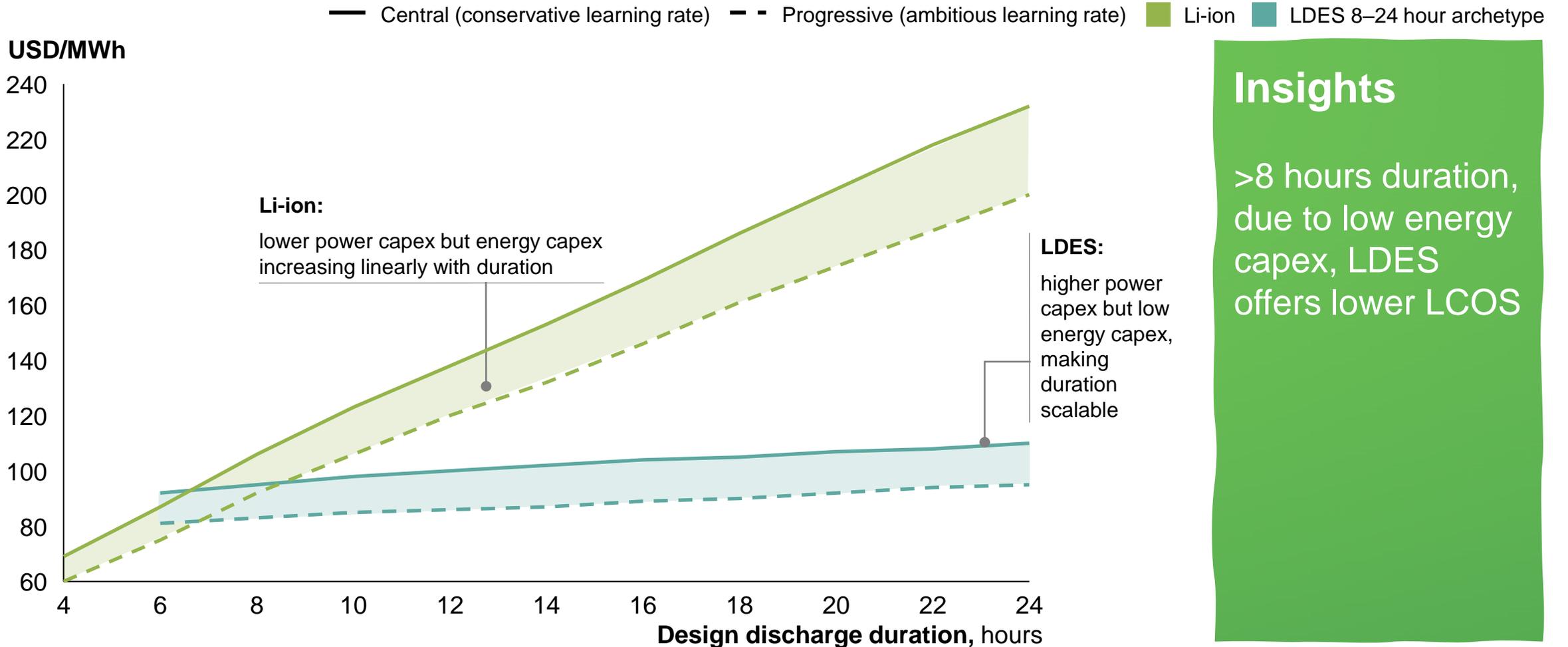
Insights

LCOS is comparable to LCOE and represents a tool for cost comparison of electricity storage

LCOS depends heavily on the operations of the system but allows a like-for-like comparison

LDES likely cost-competitive for durations >6-8 hours

2030 energy storage LCOS competitiveness by duration for selected technologies (USD/MWh)

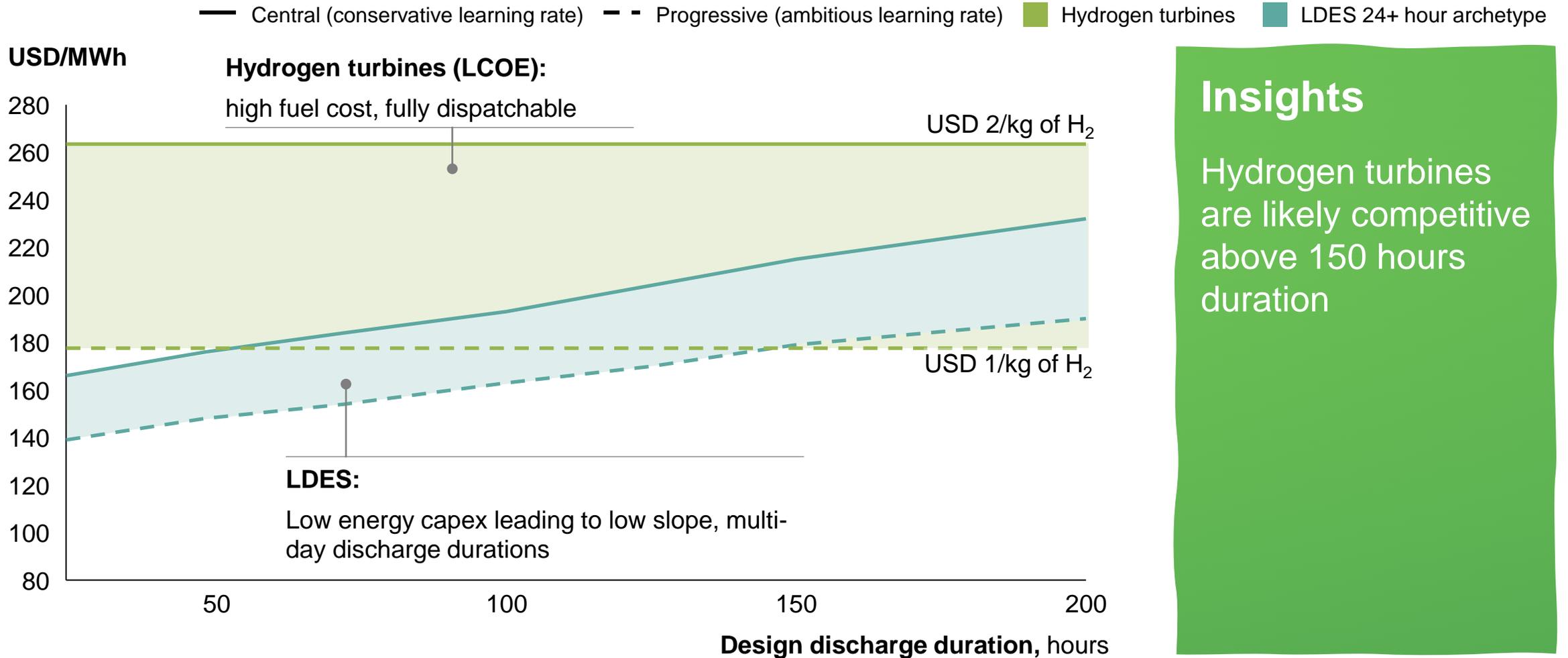


Insights

>8 hours duration, due to low energy capex, LDES offers lower LCOS

LDES likely cost-competitive for discharge durations <100-150 hours

2030 energy storage LCOS competitiveness by duration for selected technologies (USD/MWh)



Insights

Hydrogen turbines are likely competitive above 150 hours duration

Seven drivers of potential value for LDES assets – note that only a subset of these will apply depending on the application

T&D optimization

Savings from replacing costly transmission build-out with relatively more cost-efficient investment in storage¹

Capacity provision

Capacity payments for availability of dispatchable power

RE curtailment reduction

Revenues from storing and discharging otherwise curtailed renewable energy,¹ under limited transmission capacity

Grid support

Compensation for offering grid stability services² as conventional generation plants (e.g., coal) – which traditionally offer stability – are phased out

Firmed PPA premiums

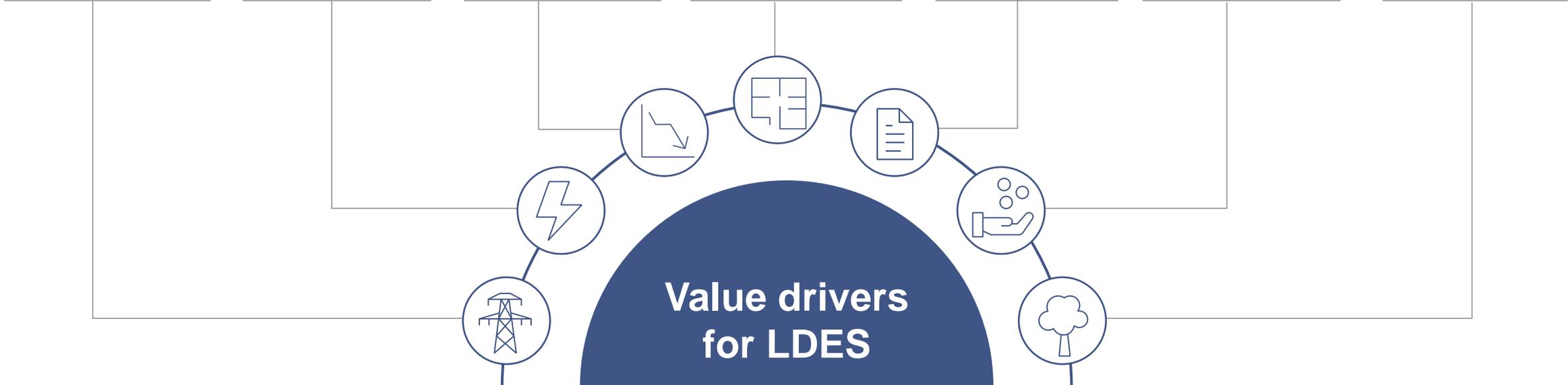
Premiums paid by customers with targets on 100% RE looking to, e.g., decarbonize operations, hedge market volatilities

Production cost savings

Electricity production cost savings, e.g., from replacing onsite diesel generation

CO₂e cost savings

CO₂e cost savings originating from reducing/displacing existing fossil generation and not having to pay a carbon price for the associated emissions



1. Including cost savings on compensation paid to curtailed RE suppliers and redispatched power suppliers (depending on local regulatory regime)

2. Stability services include: short circuit, dynamic voltage control, inertia

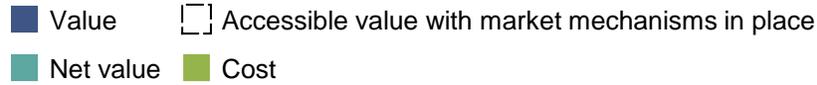
Business cases for diverse LDES use cases explored

Customer example	IRR 2025 (potential improvement)	Value drivers for LDES						
		T&D optimization	Capacity provision	RE curtailment reduction	Grid support	Firmed PPA premiums	Production cost savings	CO ₂ e cost savings
Integrated utilities with significant RE build-out and transmission bottlenecks	~3% (+11%)	Applies to case study	Applies to case study	Applies to case study	Applies to case study	Does not apply	Does not apply	Applies to case study
RE developers or owners selling corporate RE PPAs with firmed capacity	~7%	Does not apply	Does not apply	Does not apply	Does not apply	Applies to case study	Does not apply	Does not apply
Isolated island power systems	~7% (+5%)	Does not apply	Does not apply	Does not apply	May apply for larger systems	Does not apply	Applies to case study	Applies to case study
Industrial customers (e.g. mine)	~15% (+4%)	Does not apply	Does not apply	Does not apply	May apply for larger systems	Does not apply	Applies to case study	Applies to case study

1| A US case study shows how integrated utilities can benefit from multiple LDES applications but face uncertainty on monetization



Case example: US-based utility



Customer profile

- Integrated utility in the US that depends on gas-peaking plants for reliability
- Geographic divide between generation and demand with transmission bottlenecks
- Challenges building new transmission
- LDES assets to displace gas-peaker plants and improve RE utilization
- Potential LDES system: 200 MW/2,000 MWh (10 hours); systems of longer durations are also seeing demand driven by utilities' long-term needs

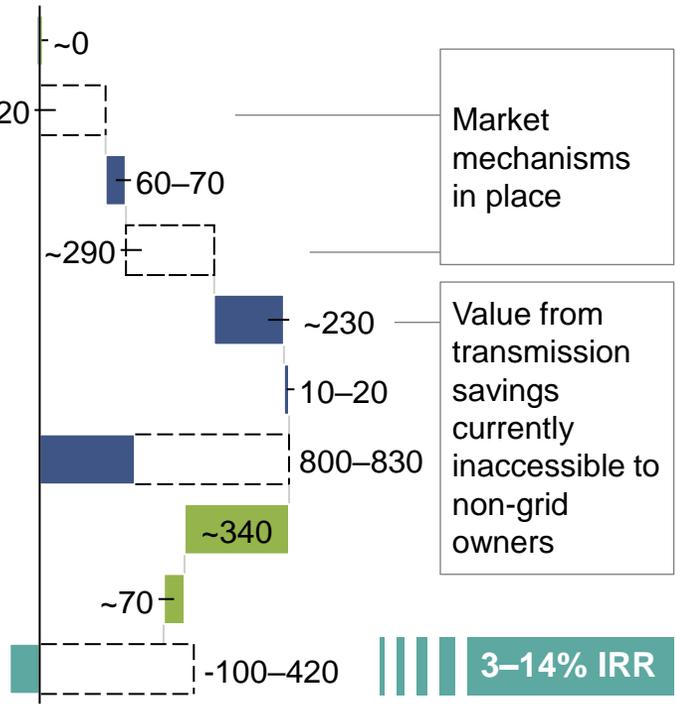
NPV for an integrated utility customer, USD millions

- Net production cost savings
- CO₂e cost savings¹ 210–220
- RES curtailment reduction
- Capacity provision
- T&D optimization
- Stability services provision

Total value creation

- Invested capital
- Total fixed O&M

NPV



Market mechanisms in place

Value from transmission savings currently inaccessible to non-grid owners

Key unlocks

Range of NPV is USD 100 mn to 420 mn, of which most comes from transmission optimization, capacity provision, and CO₂e cost savings

To access the higher end of this range, market mechanisms would have to be fully in place to ensure the benefits can be captured, e.g., for transmission owners not permitted to own storage assets

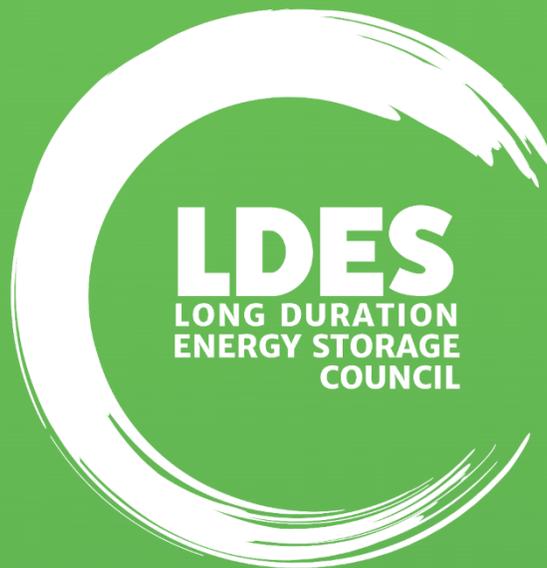
Assumptions

Final investment decision date	Commercial operation date	CO ₂ e price scenario	WACC
2023	2025	Base case	6%



1. CO₂e cost savings originate from the opportunity of replacing a gas peaking plant with LDES





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The analysis uses the McKinsey Power Model and 10,000+ data points from tech providers

Country requirements and constraints
(electrification, CO2, RPS, policy)



Exogenous fuel demand (e.g., H2, EV charging)



Asset cost and technology performance



Assumptions from other sources (e.g., NREL, BNEF, H2 Council)



NREL
NATIONAL RENEWABLE ENERGY LABORATORY
BloombergNEF
Hydrogen Council

MPM Model optimization



Lowest cost pathway for net zero power system



Total addressable market for LDES



Capacity and generation mix, incl. flexibility



Societal cost savings



Investment required



MPM determines which **investments and operating decisions minimize costs** to meet net zero targets

10,000+ data points from members processed by independent clean team

Coupled with deep insights from Council members, McKinsey, external experts

Respected public sources leveraged

Many technological approaches tackle the same fundamental need

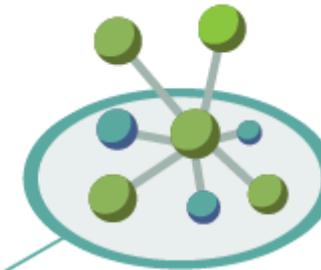
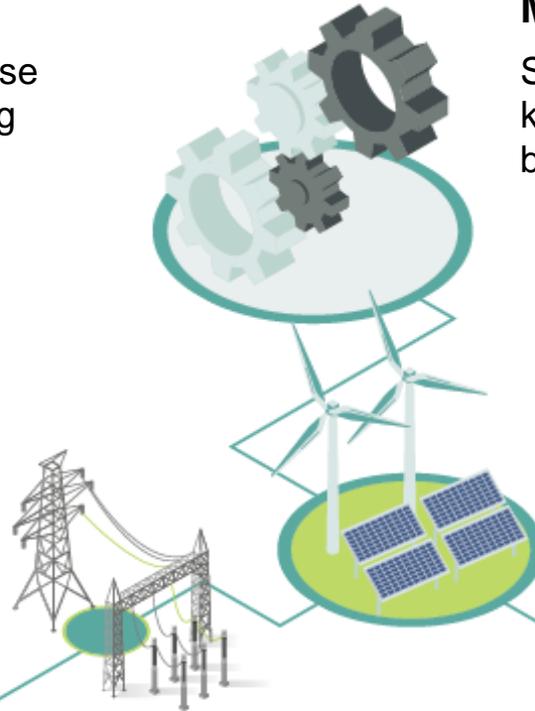
Thermal

Store energy thermally to release electricity and heat (e.g. sterling engines, molten salt)



Mechanical

Store gravitational potential or kinetic energy (e.g., PSH, gravity based, CAES, LAES, Liquid CO₂)



Electrochemical

Batteries of different chemistries that store electrical potential energy (e.g., air-metal, flow batteries)

Chemical

Store energy in chemical bonds (e.g., H₂, power to gas to power)

Significant opportunity for LDES across major power markets

Summary of bulk power modeling results in key regions

■ Before 2030 ■ 2030–40

